NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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TECHNICAL NOTE

No. 1091

AN ANALYSIS OF THE MAIN SPRAY CHARACTERISTICS

OF SOME FULL-SIZE MULTIENGINE FLYING BOATS

By F. W. S. Locke, Jr.
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SUMMARY

An analysis is made of available full-scale and model data on the height of the main spray at the propeller plane of multiengine flying boats. It is found that, with fixed C_{Δ_0} and L_f/b, increasing the beam will increase the spray height at a slightly greater rate than would be expected by Froude's Law.

By adjusting the data to a common beam, a good correlation of spray height and forebody length/beam ratio is obtained. This correlation indicates a very appreciable reduction in spray height can be obtained by increasing L_f/b.

Appropriate combination of the correlations provides a design chart which will enable determination of the necessary hull height to keep the propellers clear of the main spray. This chart is specifically for multiengine flying boats of generally conventional design.

INTRODUCTION

The increasing size and weight of modern flying boats has emphasized the absolute necessity of obtaining good water performance in new designs. In the past, a great deal of trouble has been caused by spray. Propellers, flaps, and tail surfaces have been seriously damaged by impact with spray in relatively smooth water, and vision through the windshield has been badly obscured by spray thrown up the bow in rough water. It would be very desirable to have means for predicting the height of the spray as affected by the load and dimensions of proposed designs.

It is pointed out in reference 1 that spray has two principal

origins: (1) The "main spray," which exists in smooth and rough water, originates from the rear 80 percent or so of the forebody; and (2) the "bow spray," which normally can be avoided except in rough water, originates from the forward sections of the forebody.

Parkinson (reference 2) correlated some full-scale experience on main spray in terms of the forebody length/beam ratio and a spray "intensity" constant. However, since his correlation does not include spray height, it would be possible to design a hull having a low value of the spray-intensity constant and unknowingly locate the propellers so that they were operating in the spray. In other words, the actual combination of hull and airplane must be considered as a unity. Because of the importance of spray height, it is the purpose of the work considered in this report to attempt to determine a correlation for the main spray height in relatively smooth water. The correlation is based on quantitative full-scale data on the spray height at the propellers of multiengine flying boats. No quantitative full-scale data are available at other locations, which, fortunately, are of somewhat less importance.

By using the correlation it should be possible to predict a hull height which will ensure propeller clearance. Hence, the spray intensity will be of less importance, provided, of course, the hull size is not decreased ad absurdum.

DATA

On full-size multiengine flying boats, the height of the main spray in relatively smooth water is difficult to estimate, anywhere but at the propeller plane. The location of the propeller disk is known, so that the height of the spray at this point may be estimated with reasonable accuracy. Under practically all conditions a very light mist of spray will be drawn up by the propellers, but when the heavy green water strikes the propeller, it can be felt as well as seen. It is the heavy main spray entering the propeller in smooth water, and not a light mist, with which this report is concerned.

Most of the data were taken from flight test reports. The data are taken from experience in relatively smooth water and with the aircraft headed directly into the wind. All longitudinal accelerations were very low. The spray was observed by eye with reference to the propeller disk and hence, while subject to a fairly large degree of error, may be considered quantitative. In addition, various people who either had flown the airplanes or been concerned with their operation were consulted. Reasonably good agreement of opinions was obtained.

The data, together with pertinent particulars of the various flying boats, are tabulated in table I.

NOTATION

Throughout this report the following notation and nondimensional coefficients are used:

Initial load coefficient	$C_{\Delta_o} = \Delta_o/wb^3$
Speed coefficient	$C_V = V/\sqrt{gb}$
Weber number	$\gamma/\rho bV^2$ or γ/wb^2
Longitudinal spray coefficient	$C_X = X/b$
Vertical spray coefficient	$C_Z = Z/b$
Spray height coefficient	C_Z/C_{Δ_o}
Forebody length coefficient	L_f/b

where

Δ_o initial load on the water, pounds

w specific weight of water, pounds per cubic foot (64.0 for sea water)

b beam at main step, feet

V speed, feet per second

g acceleration of gravity, 32.2 feet per second per second

γ surface tension coefficient of water, pounds per foot

ρ mass density of water, pounds second^2 per foot^4

X longitudinal position of main spray peak, measured fore (positive) or aft (negative) of the main step, feet

Z vertical position of main spray peak measured from the tangent to the forebody keel at the main step, feet

L_f forebody length, measured from the intersection of chine and keel to the step centroid along a line parallel to the tangent to the keel at the step, feet

Figure 1 defines the principal dimensions used. For the full size data considered herein, X is the distance of the bottom of the propeller arc ahead of the main step, and Z is the maximum height of the heavy spray at that point above the tangent to the forebody keel.

ANALYSIS

None of the flight test reports consulted gave a definite speed at which the spray through the propellers was at its worst, though they all stated that it was a fairly low speed - around 15 to 20 knots. Examination of model data indicates that the worst spray in the propellers should occur between about $C_V = 1.5$ and 2.0. Since this speed is so low, no very appreciable error is introduced by assuming that the load on the water is equal to the gross weight, for worst spray at the propeller plane.

In reference 3, it is shown that when $C_X/C_\Delta{}^{1/3}$ is fixed, the spray height coefficient C_Z/C_Δ will also be constant for most models. It will be noted from table I that, while the variations of C_{Δ_o} on a given flying boat are not large, C_Z/C_{Δ_o} appears to be practically constant for any particular full-size hull. Thus, despite the inconsistency of the relation C_Z/C_{Δ_o}, which is discussed in reference 3, it appeared to be quite suitable for handling full scale data.

For all the flying boats considered $C_X/C_{\Delta_o}{}^{1/3}$ at the propeller plane is reasonably close to 1.5, and the variations of gross load in practice on any of the given airplanes do not alter its value appreciably.

A plot (fig. 2) of C_Z/C_{Δ_o} against L_f/b for $C_X/C_{\Delta_o}{}^{1/3} = 1.5$ was prepared from the data for the series of models derived systematically from the XPB2M-1, and given in reference 4. On this same figure is plotted the available full-scale data from table I. In every case, the model value is lower than full scale, contrary to expectations by Froude's Law. However, in only one case, the XPB2M-1R, was there reasonably close similarity in hull form between the family of models and full scale. (The XPB2M-1R has somewhat more forebody chine flare than the XPB2M-1 and less afterbody chine flare.) The chart, figure 3, shows the difference between the full scale and model values of C_Z/C_{Δ_o} plotted against the full-size beam.

With the aid of figure 3 all the values of C_Z/C_{Δ_o}, both model and full size, were adjusted to a beam of 10 feet, and plotted against the forebody length/beam ratio on figure 4. This chart indicates a fairly

good correlation of the spray height coefficient, against L_f/b; so a final design chart was prepared. The design chart (fig. 5), shows contours of C_Z/C_{Δ_0} against L_f/b with full-size beam as the parameter. It was derived by combining figures 3 and 4.

DISCUSSION

The way in which the line was drawn through the data on figure 3 requires explanation. The three black points are for "dirty" boats. The original S-43 was cleaned up appreciably by the addition of powerful spray strips on the forebody. The J4F-2 has no chine flare, but only a small spray strip, and is very "dirty." The RCAF is understood to have installed spray suppressors on this aircraft but their data on the result are not available. Since the Saro 37 also falls a long way above the curve on figure 3, it is presumed that it should also be classed as a "dirty" hull.

Figure 3 indicates that the differences in the model and full-size spray height, though numerically small, are sufficiently large to be of practical importance. The exact cause of the difference is not at all clear. (It should be noted that the models (from reference 4) were tested without motor-driven propellers, and hence their results do not include any effect of slipstream. Thus the difference may be due to the slipstream. However, it is just as reasonable to assume that the differences in model and full-scale spray height are due only to differences in the surface tension number (Weber number).) The fact that it is possible to plot the correction against the beam would appear to support this idea. In reference 6 some experience is recorded which indicates that heel angle may be the source of much of the difference. When the model was heeled, the spray was appreciably higher relative to the model. Actually the difference between model and full scale probably is due to a combination of all of these effects. Sottorf's data (reference 5), also obtained from models without running propellers, indicate a far more rapid increase of spray height with increasing size than is shown here. Because a survey (reference 6) of change of spray height with size indicated that no pronounced difference need be expected, and this is supported by the present investigation, Sottorf's results have been neglected.

Within the limits of about 15° to 25° (reference 6) dead rise does not have much effect on the spray at the propeller plane, but increasing the dead rise does produce a beneficial reduction of spray at the flap location. In using model data to determine spray height, despite the uncertainties involved in this correlation, the use of the addition

given by figure 3 at longitudinal locations other than $C_X/C_{\Delta_0}{}^{1/3} = 1.5$ probably is justified, at least until better information becomes available.

The amount of chine flare on the forebody will influence the spray height in smooth water according to both model and flight tests. However, both model and full-scale flight tests also indicate that in rough water pronounced chine flare has very little effect, and in fact sometimes may be even harmful. Hence, a designer can count on some reduction of spray in smooth water over that shown by figure 5 by using pronounced chine flare, but should not expect a proportional reduction in rough water.

The BV222 is a good example of what might happen by using Parkinson's criterion (reference 2) alone: 65,000 pounds is approximately the limiting weight which can be carried without excessive spray through the propellers, yet Parkinson's K_2, $C_{\Delta_0}/(L_f/b)^2$, is equal to the very low value of 0.0414. At the design weight of 99,000 pounds the aircraft is reported to be very dirty. A later design, the BV238, has almost the same hull proportions except that the propellers are located a good deal farther above the keel. This is mentioned to emphasize the necessity of fitting aircraft and hull together so that the combination will give satisfactory performance, and the fact that having a lightly loaded hull is not sufficient to ensure desirable spray characteristics.

The design chart (fig. 5) should be very useful in preliminary design, provided the forebody form at least resembles those on which the chart is based. The chart does not necessarily represent optimums obtainable with conventional forebodies, because both afterbody angle and afterbody length are known to have fairly large effects on the spray characteristics through their influence on the forebody trim. However, by using the design chart, the designer can determine hull heights, for a given propeller clearance, with various forebody dimensions. He can then determine the influence of the forebody on the performance of the airplane he is designing, with specified spray clearance to take-off. With the aid of information obtained from figure 5 a good framework can be obtained in which to make a design study for a proposed airplane.

The data in this report were obtained from multiengine flying boats. Because the reason for the difference between model and full-size spray height is not clear, the design chart produced from the data is strictly applicable only to multiengine flying boats of generally conventional configurations.

It will be noted that the design chart (fig. 5) will lead to much lower load coefficients than have generally been used in past practice, regardless of the forebody length/beam ratio. This will result in conservative designs. However, it is very desirable that further work be

done to correlate accurately model and full-scale spray in order to put the process of prediction on a firmer foundation. This will take a good deal of time. In the interim, the data in this report should prove useful.

CONCLUSIONS

Analysis of available model and full scale data on the height of the main spray at the propeller plane, in relatively smooth water, indicates:

1. C_Z/C_{Δ_o} is a constant for a given hull.

2. With a fixed L_f/b, C_Z/C_{Δ_o} increases slowly with increasing beam.

3. With a fixed beam, C_Z/C_{Δ_o} decreases rapidly with increasing forebody length.

Bureau of Aeronautics, Navy Department,
Washington, D. C., October 1945.

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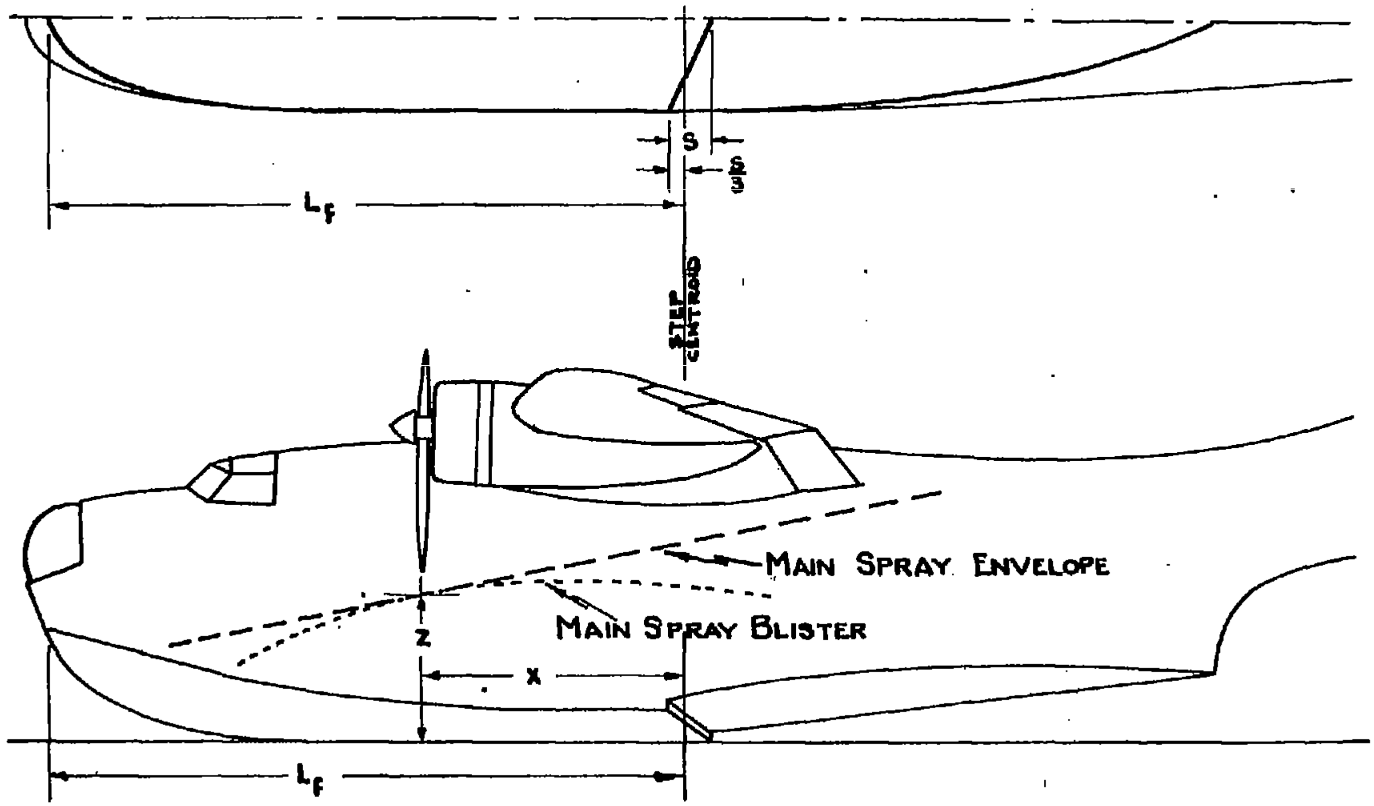
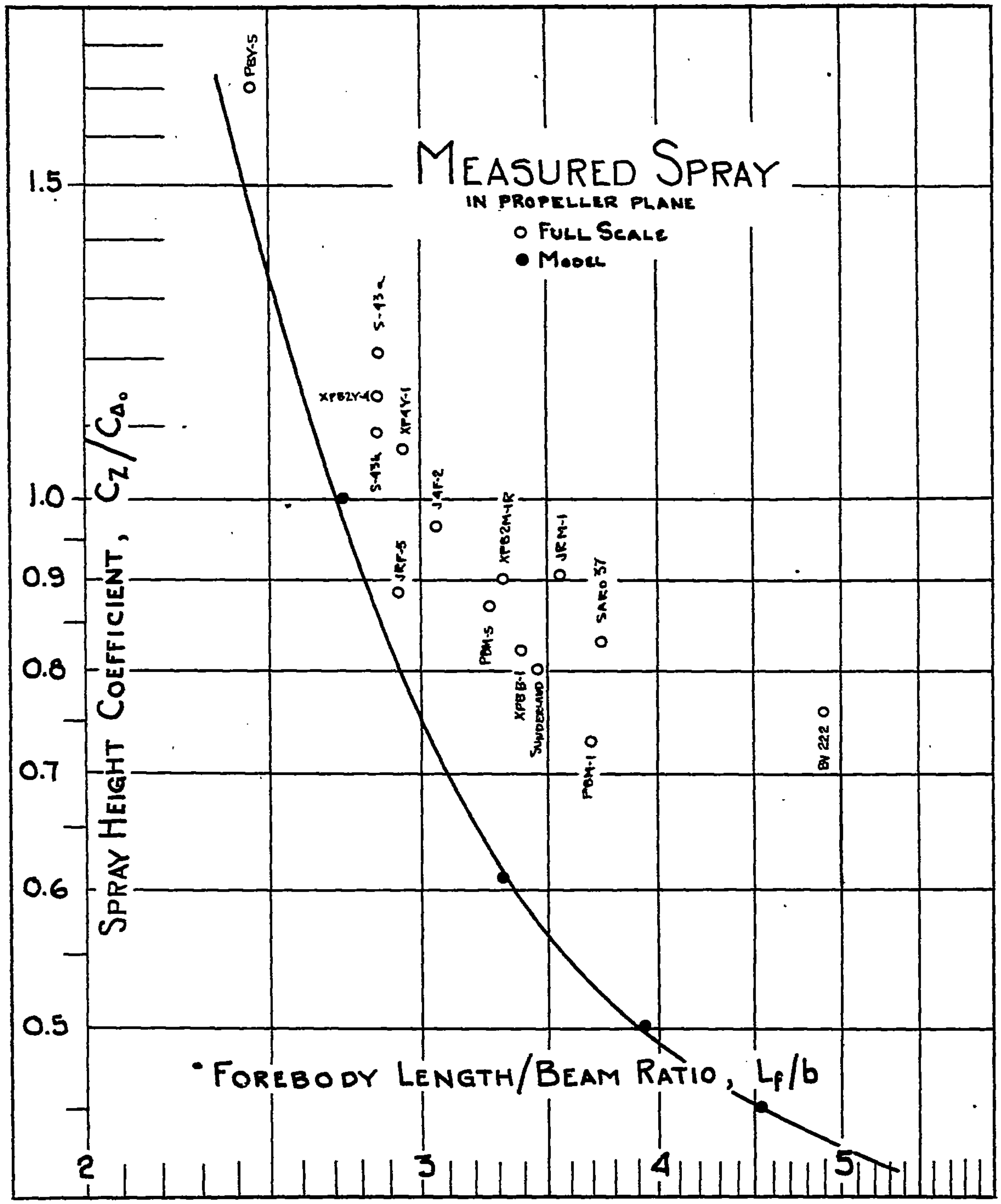
TABLE I.- MAIN SPRAY CHARACTERISTICS

Manufacturer	Model	No. of engines	Beam (ft)	Fore-body length (ft)	Δ_o (lb)	C_{Δ_o}	L_f/b	Full scale C_Z	Full scale C_X	Full scale $\frac{C_Z}{C_{\Delta_o}}$	Full scale $\frac{C_X}{C_{\Delta_o}^{1/3}}$	Equivalent model C_Z/C_{Δ_o}	$\delta(C_Z/C_{\Delta_o})$	Remarks	Source of data
SARO	37	4	4.13	15.5	5,700	1.28_5	3.75	1.06	1.37	0.82_5	1.26	0.52_5	0.30_5	Propellers just touching heavy spray	MAEE
					6,250	1.41		1.18		.84	1.22			6 in. of propellers in heavy spray	
GRUMMAN	JRF-2	2	4.25	13.0	4,200	.86	3.06	.83	1.66	$.96_5$	1.75	.72	$.24_5$	4 in. of propellers in heavy spray	ADR test
GRUMMAN	JRF-5	2	5.00	14.65	9,250	1.19	2.93	1.05	1.66	$.88_5$	1.56	.80	$.08_5$	10 in. of propellers damaged in fresh water	ADR test
SIKORSKY	S-43 (a)	2	7.50	21.25	19,000	.70	2.84	.85	1.42	1.21		.87	.34	Max. load for hull with no spray strips	FORMER PAA employee
	S-43 (b)	2			21,000	.78		.85	1.42	1.09	1.55	.87	.22	Max. load with spray strips for clean propellers	
MARTIN	PBM-1	2	8.52	31.5	48,000	1.21	3.70	.89	1.58	.73	1.48	.53	.20	Propellers just touch heavy spray	MARTIN tests
SHORT	SUNDERLAND	4	9.10	31.6	56,000	1.16	3.47	.93		.80		$.57_5$	$.22_5$	Largest load which will not damage propellers	MAEE
CONSOLIDATED	XP4Y-1	2	9.17	27.0	37,500	.76	2.94	.81	1.38	1.07	1.51	$.79_5$	$.27_5$	Propellers just clear heavy spray	CVAC tests
MARTIN	PBM-5	2	10.00	32.8	50,000									Good clearance	MARTIN and U.S. Navy flight tests
					55,000	.86	3.28	.75	1.47	.87	1.55	.63	.24	Propellers just clear heavy spray	
					60,000									Propellers in heavy spray	
BLOHM and VOSS	222	6	10.11	49.4	68,000	1.03	4.88	.79	1.79	.76	1.77	$.43_5$	$.32_5$	Heavy spray wets about 6 in. of propellers	U.S. Navy tests
CONSOLIDATED	PBY-5	2	10.17	24.8	30,000	.45	2.44	.75	1.52	1.67	1.98	1.45	.25	Spray about same height as propellers	U.S. Navy and RAF
					35,000	.42		.90		1.73	1.89			Spray 1-1/2 ft above bottom of propellers	
BOEING	XPBB-1	2	10.42	35.4	65,000									Only fine spray in propellers	U.S. Navy flight tests
					70,000	.97	3.40	.79	1.51	.82	1.53	$.59_5$	$.22_5$	Spray about same height as propellers	
					75,000									Propellers in heavy spray	
CONSOLIDATED	XPB2Y-4	4	10.50	29.9	66,000	.89	2.85	1.02	1.64	1.15	1.71	.86	.28	2.8 ft of propeller arc in heavy spray	CVAC tests
					70,000	.94		1.05		1.12	1.67			3.1 ft of propeller arc in heavy spray	
MARTIN	XPB2M-1R	4	13.50	44.8	148,500	.94	3.32	.84	1.59	$.89_5$	1.62	$.61_5$	.29	About 1 ft clearance at propellers	NATS
					155,000	.99		.90		.91	1.59			Estimate propellers would just touch heavy spray	
MARTIN	JRM-1	4	13.50	48.1	110,000	.70	3.57	$.63_5$	1.63	$.90_5$	1.83	$.55_5$	.35	3-1/2 ft clearance at propellers	MARTIN and NAVY



SCHEMATIC SKETCH TO ILLUSTRATE
DEFINITIONS OF DIMENSIONS
FIGURE 1



MEASURED SPRAY
IN PROPELLER PLANE
o FULL SCALE
• MODEL
SPRAY HEIGHT COEFFICIENT, C_Z/C_{Δ_0}
FOREBODY LENGTH/BEAM RATIO, L_f/b
1.5
1.0
0.9
0.8
0.7
0.6
0.5
2
3
4
5
PBY-5
S-43
XPB2Y-4
XP4Y-1
S-43
JRF-5
XPB2M-1R
JRM-1
SARO 37
PBM-5
XPBB-1
SUNDERLAND
PBM-1
BV 222

FIGURE 2

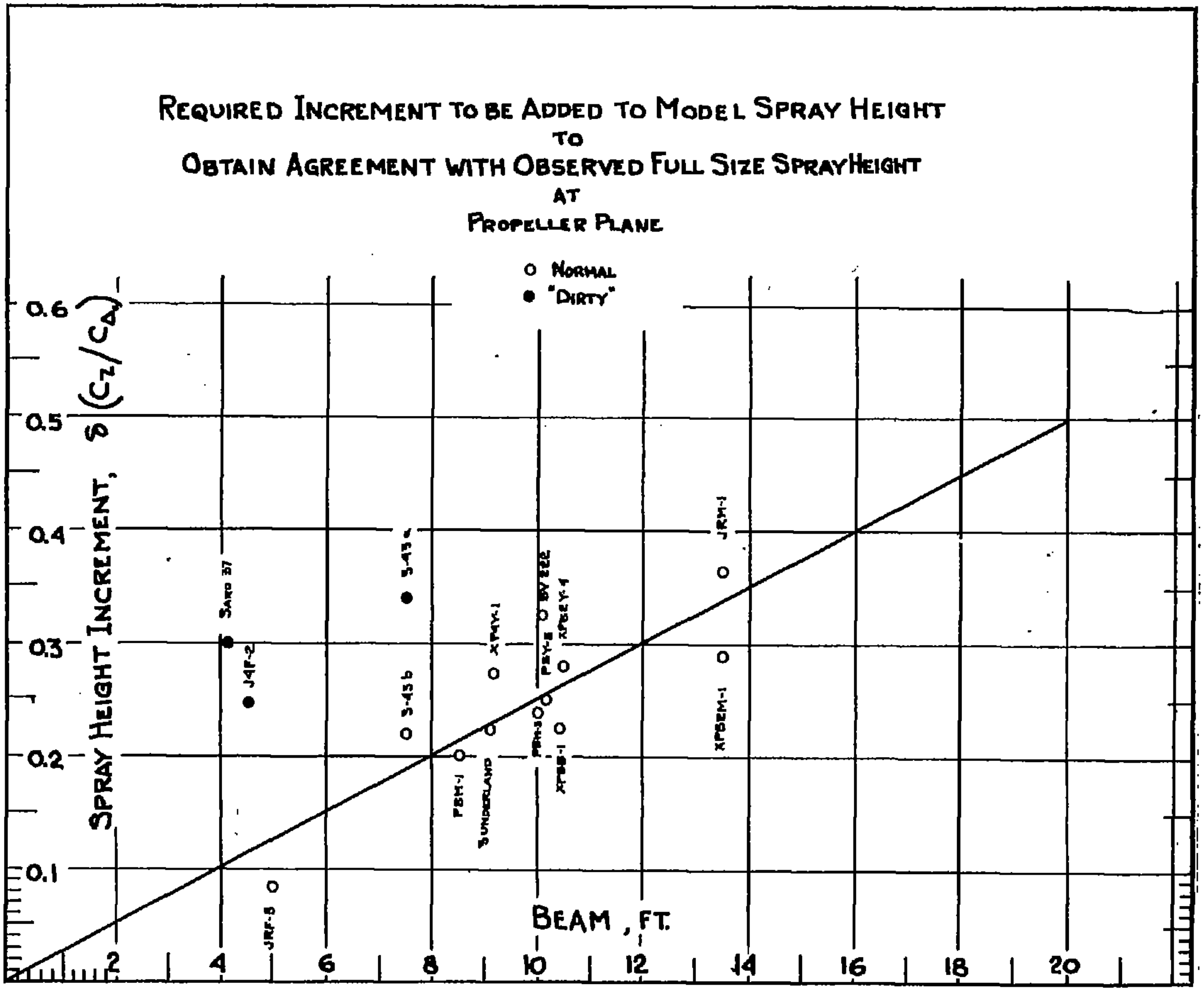

REQUIRED INCREMENT TO BE ADDED TO MODEL SPRAY HEIGHT
TO
OBTAIN AGREEMENT WITH OBSERVED FULL SIZE SPRAY HEIGHT
AT
PROPELLER PLANE
O NORMAL
● "DIRTY"
SPRAY HEIGHT INCREMENT, $b\,(C_Z/C_\Delta)$
BEAM, FT.
0.1
0.2
0.3
0.4
0.5
0.6
2
4
6
8
10
12
14
16
18
20
J4F-2
JRF-5
S-43 b
XP4Y-1
PBY-5
BV 222
PBM-1
SUNDERLAND
PBM-3
XPBB-1
JRM-1
XPB2M-1

FIGURE 3

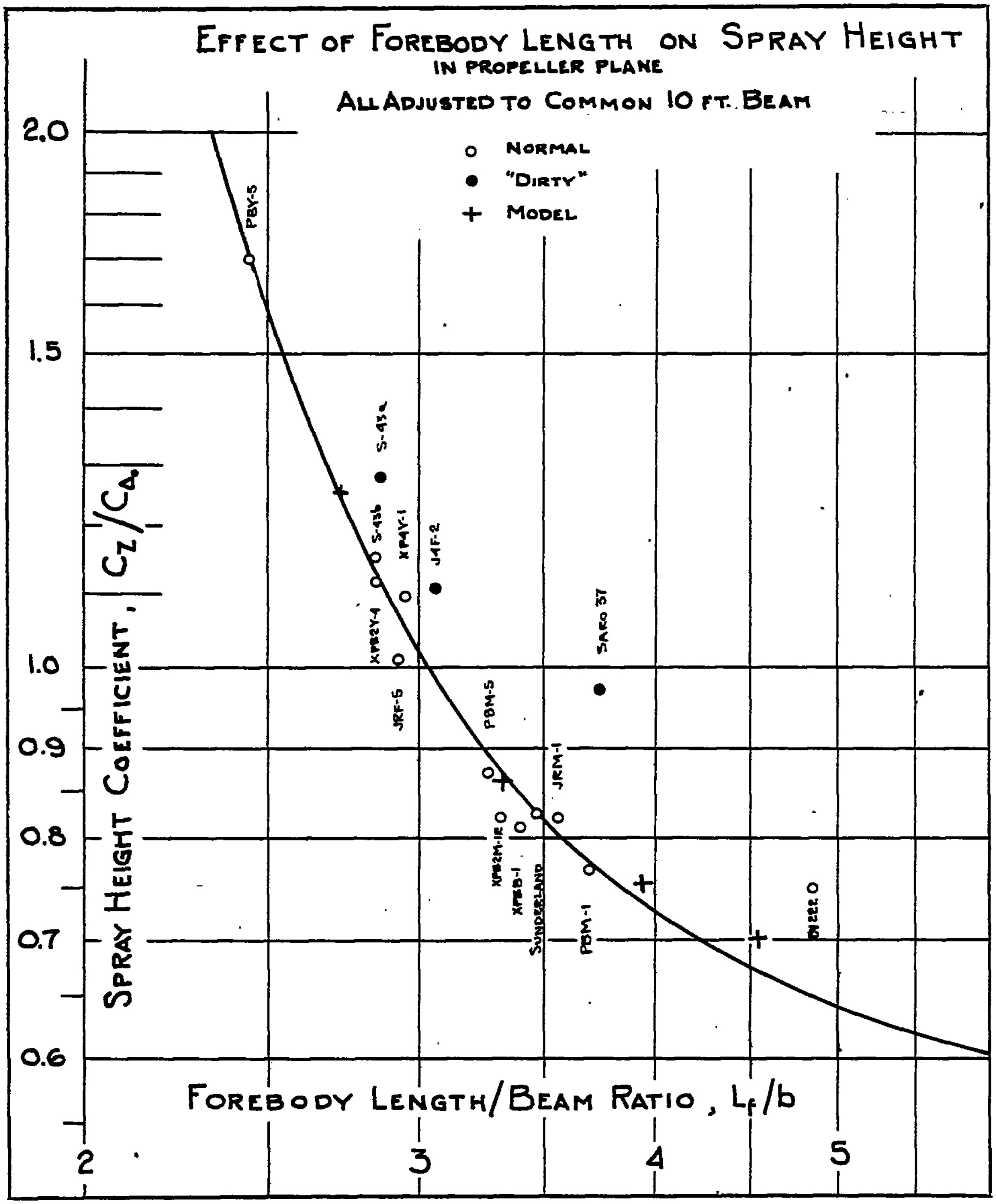

EFFECT OF FOREBODY LENGTH ON SPRAY HEIGHT
IN PROPELLER PLANE
ALL ADJUSTED TO COMMON 10 FT. BEAM
NORMAL
"DIRTY"
MODEL
SPRAY HEIGHT COEFFICIENT, C_Z/C_Δ
FOREBODY LENGTH/BEAM RATIO, L_f/b
2.0
1.5
1.0
0.9
0.8
0.7
0.6
2
3
4
5
PBY-5
S-43a
S-43b
XP4Y-1
J4F-2
XPB2Y-4
JRF-5
SARO 37
PBM-5
JRM-1
XPB2M-1R
XPBB-1
SUNDERLAND
PBM-1
DO-222

FIGURE 4

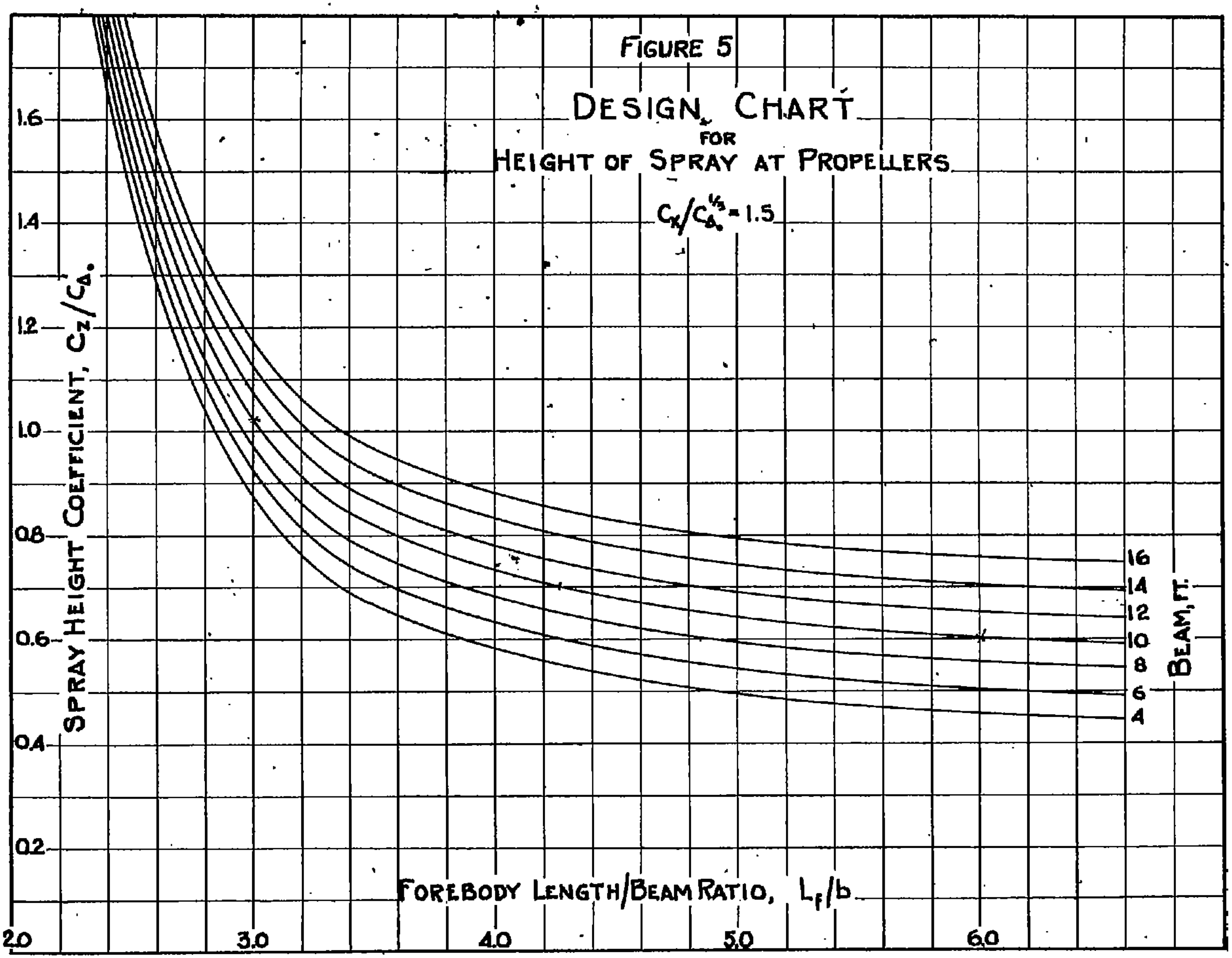


FIGURE 5
DESIGN CHART
FOR
HEIGHT OF SPRAY AT PROPELLERS
$C_V/C_{\Delta_0}^{1/2} = 1.5$
SPRAY HEIGHT COEFFICIENT, C_Z/C_{Δ_0}
FOREBODY LENGTH/BEAM RATIO, L_f/b
BEAM, FT.
16
14
12
10
8
6
4
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
2.0
3.0
4.0
5.0
6.0